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Dated: Dec. 7, 2006 Signature: (Reza Mollaaghababa)

Docket No.: 101328-177
(PATENT)

BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

In re Application of:

Qing Hu et al.

Application No.: 10/661,832

Confirmation No.: 7715

Filed: September 12, 2003

Art Unit: 2828

For: METAL WAVEGUIDES FOR MODE CONFINEMENT IN TERAHERTZ LASERS AND AMPLIFIERS

Examiner: Tod Thomas Van Roy

APPEAL BRIEF PURSUANT TO 37 C.F.R. § 41.37

MS Appeal Brief - Patents
Commissioner for Patents
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Dated: December 7, 2006 Signature: ____________ (Reza Mollaaghababa)

Docket No.: 101328-0177
(PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:
Qing Hu et al.

Application No.: 10/661,832 Confirmation No.: 7715

Filed: September 12, 2003 Art Unit: 2828

For: METAL WAVEGUIDES FOR MODE CONFINEMENT IN TERAHERTZ LASERS AND AMPLIFIERS

Examiner: T. T. Van Roy

RESPONSE TO NOTIFICATION OF NON-COMPLIANCE

MS Appeal Brief - Patents
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

In response to the Notification of Non-Compliant Appeal Brief, Applicants file the attached revised Appeal Brief. The Original Appeal Brief filed with the U.S. Patent Office on October 23, 2006 included an explanation of each of the independent claims 1, 15, and 18 in a section entitled "SUMMARY OF CLAIMED SUBJECT MATTER." The attached revised Appeal Brief identifies, for each of these independent claims, the portions of the specification, as well as figures, which provide support for that claim.

Further, the revised Appeal Brief includes headings "IX. Evidence Appendix" and "X. Related Proceeding Appendix," with a note under each heading indicating that no evidence appendix or related proceeding appendix is provided.

Moreover, in the Arguments section, the revised Appeal Brief identifies each ground of rejection with reference to the applicable statute.

Accordingly, the revised Appeal Brief comports with the requirements of 37 CFR 41.37.

Dated: December 7, 2006

Respectfully submitted,

By__________________________

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I. REAL PARTY IN INTEREST

The real party in interest is the Massachusetts Institute of Technology ("MIT") located in Cambridge, Massachusetts. MIT derives its rights in this application by virtue of an assignment of the application by the inventors thereto.

II. RELATED APPEALS AND INTERFERENCES

None.

III. STATUS OF CLAIMS

Claims 1-18 are currently pending in the present application, Serial Number 10/661,832. According to the Final Office Action mailed on February 21, 2006, each of the claims 1-18 stands finally rejected. Accordingly, claims 1-18 are subject to this appeal.

IV. STATUS OF AMENDMENTS

No amendments have been filed subsequent to the final rejection.

V. SUMMARY OF CLAIMED SUBJECT MATTER

The present invention is generally directed to quantum cascade lasers and amplifiers that operate in the terahertz region of the electromagnetic spectrum, and methods for generating terahertz radiation. In particular, the invention generally relates to utilizing double-sided metal waveguides in quantum cascade lasers and amplifiers for efficient generation of electromagnetic radiation in a frequency range of about 1 terahertz to about 10 terahertz.

To fully understand the claimed invention, it is helpful to appreciate the state-of-the art at the time of the Applicants' invention, which represents the background against which the claimed invention was developed.

A. THE PROBLEM ADDRESSED BY THE INVENTION IS THE SCARCITY OF COHERENT TERAHERTZ RADIATION SOURCES IN A FREQUENCY RANGE OF ABOUT 1 TO ABOUT 10 TERAHERTZ AND EFFICIENT METHODS FOR MODE CONFINEMENT IN SUCH TERAHERTZ LASERS

Coherent radiation in the terahertz (THz) region (e.g., ~1-10 THz, corresponding to a wavelength λ=30-300 μm or a photon energy $h\omega$=4-40 meV) of the electromagnetic spectrum

has potential applications in a variety of fields such as chemical and biological spectroscopy, plasma diagnostics, and detection of bio- and chemical agents and explosives in security applications. The number of coherent THz radiation sources operating in this region, however, remain scarce. By way of example, the use of conventional semiconductor laser diodes for generating radiation in the range of 1 THz to 10 THz is impractical. Semiconductor devices such as Gunn oscillators and Schottky-diode frequency multipliers utilize classical real-space charge transport for generating radiation. The power levels of these devices decrease as the fourth power of radiation frequency ($\frac{1}{f^4}$) as the radiation frequency (f) increases above 1 THz. Further, photonic or quantum electronic devices, such as laser diodes, are limited by the semiconductor energy bandgap, which is typically higher than 10 THz.

Unipolar quantum well semiconductor devices that lase in the mid-infrared portion of the electromagnetic spectrum are known. A mid-infrared quantum cascade laser (QCL) operating at a wavelength of 4 microns was developed at Bell Laboratories in 1994, and since then, there have been major improvements in power levels, operating temperatures, and frequency characteristics for the mid-infrared range. In addition, mode confinement using plasmon waveguides has been successful in this frequency range.

However, the small separation of lasing energies in the frequency range of about 1 to about 10 THz, (on the order of 10 meV) renders the development of lasers operating in this range more challenging. There are also problems with using conventional surface plasmon waveguides for mode confinement in this frequency range.

Accordingly, a need exists for the development of coherent THz radiation sources. Further, a need exists for a method of confining the THz radiation modes so as to maintain lasing while achieving a low threshold current density, a higher operating temperature, and a higher output power.

B. THE INVENTION SOLVES THE PROBLEM BY PROVIDING QUANTUM CASCADE LASERS AND AMPLIFIERS WITH DOUBLE-SIDED METAL WAVEGUIDES FOR EFFICIENT GENERATION OF RADIATION IN A FREQUENCY RANGE OF ABOUT 1 TO ABOUT 10 TERAHERTZ

The claimed invention is generally directed to quantum cascade lasers and amplifiers that operate in the terahertz region of the electromagnetic spectrum and methods for efficient generation of electromagnetic radiation in a frequency range of about 1 to about 10 THz. These QCLs and amplifiers employ double-sided metal waveguides for efficient mode confinement within an active lasing region.

In particular, independent claim 1 recites a quantum cascade laser that includes an active region for generating radiation in a frequency range of about 1 to about 10 THz and a waveguide formed of an upper and a lower metallic layer. Each metallic layer is disposed on a surface of the active region so as to confine selected modes of the lasing radiation within that region.

Support for independent claim 1 can be found, e.g., at page 2, paragraph 8, page 6, paragraphs 29, 30, 31; page 7, paragraph 32; FIGURES 1 and 2, as well as throughout the remainder of the specification.

Further, independent claim 18 recites a Terahertz amplifier that includes an amplification region for amplifying an incoming radiation signal having a frequency in a range of about 1 to about 10 THz to generate an amplified signal, an input port for coupling the incoming radiation into the amplification region, an exit port for extracting the amplified signal from the amplification region, and a waveguide formed of an upper and a lower metallic layer disposed on opposing surfaces of the amplification region to confine radiation within that region.

Support for independent claim 18 can be found, e.g., at page 4, paragraph 15; page 17, paragraph 62, FIGURE 11; as well as throughout the remainder of the specification.

Moreover, independent claim 15 recites a method of confining a mode profile of radiation in a quantum cascade laser, which comprises disposing an active region of a quantum cascade laser operating in a frequency range of about 1 THz to about 10 THz between an upper metallic layer and a lower metallic layer, wherein each metallic layer has a thickness larger than a skin depth of radiation in said frequency range of about 1 THz to about 10 THz in the metallic layer.

Support for claim 15 can be found, e.g., at page 2, paragraph 8, and page 3, paragraph 12.

VI. GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL

A. THE REJECTIONS OF CLAIMS 1-6, AND 8 PURSUANT TO 35 U.S.C. §103(A) AS BEING UNPATENTABLE OVER AN ARTICLE ENTITLED "QUANTUM CASCADE LASERS WITH DOUBLE METAL-SEMICONDUCTOR WAVEGUIDE RESONATORS," PUBLISHED IN APPL. PHYS. LETT. 80 (17) (2002) BY UNTERRAINER *ET AL.* (HEREIN "UNTERRAINER") IN VIEW OF ANOTHER ARTICLE ENTITLED "ELECTRICALLY PUMPED TUNABLE TERAHERTZ EMITTER BASED ON INTERSUBBAND TRANSITION," PUBLISHED IN APPL. PHYS. LETT. 71 (4) (1997) BY XU *ET AL.* (HEREIN "XU").

B. THE REJECTIONS OF CLAIMS 15 AND 17 PURSUANT TO 35 U.S.C. §102(B) AS BEING ANTICIPATED BY UNTERRAINER, AND FURTHER REJECTIONS OF THESE CLAIMS PURSUANT TO 35 U.S.C. §103(A) AS BEING OBVIOUS OVER UNTERRAINER IN VIEW OF XU.

C. THE REJECTIONS OF CLAIMS 1, 4, 6, 9-13, AND 18 PURSUANT TO 35 U.S.C. §103(A) AS BEING UNPATENTABLE OVER XU IN VIEW OF UNTERRAINER.

D. THE REJECTION OF CLAIM 7 PURSUANT TO 35 U.S.C. §103 AS BEING OBVIOUS OVER UNTERRAINER IN VIEW OF XU AND FURTHER IN VIEW OF PUBLISHED U.S. PATENT APPLICATION NO. 2004/0105471 OF KNEISSL ET AL. (HEREIN "KNEISSL")

VII. ARGUMENTS

A. CLAIMS 1-6 AND 8 ARE NOT OBVIOUS (35 U.S.C. §103(A)) OVER COMBINED TEACHINGS OF UNTERRAINER AND XU BECAUSE NEITHER REFERENCE TEACHES THE USE OF DOUBLE-SIDED METAL WAVEGUIDES IN QCLS OPERATING IN A RANGE OF ABOUT 1 TO 10 THZ

Independent claim 1, as presently pending in the application, recites a quantum cascade laser with an active region for generating lasing radiation in a frequency range of about 1 to about 10 THz. The claimed quantum cascade laser further includes a waveguide formed of an upper metallic layer and a lower metallic layer, where each layer is disposed on a surface of the active region so as to confine selected modes of the lasing radiation within that region.

1. Unterrainer's teachings relate to a much shorter wavelength range, and even in that range, Unterrainer teaches away from the use of double-sided metal waveguides

Unterrainer discloses quantum cascade lasers that operate at wavelengths of 19, 21, and 24 microns. However, considerations relevant to mode confinement at these radiation wavelengths are not necessarily applicable to mode confinement at much longer wavelengths recited in claim 1. In fact, the upper end of Applicants' claimed range (i.e., about 300 microns) is *more than an order of magnitude greater* than the radiation wavelengths disclosed by Unterrainer. For example, waveguide losses due to mode penetration into metallic layers can be significantly different for wavelengths that are more than an order of magnitude apart.

Moreover, even in the shorter wavelengths with which it is concerned, Unterrainer teaches *away* from utilizing double-sided metal waveguides for confining the modes of QCLs. More specifically, Unterrainer compares the use of a double-sided metal waveguide resonator with a single-sided surface plasmon waveguide (one having only one metallic layer) for use in QCLs. In particular, Figure 2 of Unterrainer, which is reproduced here, presents experimental data depicting the threshold current density as a function of operating temperature for QCLs operating at a common wavelength of 21 microns, but having different waveguide resonators. More specifically, one of the lasers employs a single-sided surface plasmon waveguide (open squares) while the other utilizes a double-sided metal waveguide (full circles) – the arrow indicates the low temperature threshold current density of an identical device with a double-sided surface plasmon waveguide. Over the entire tested temperature range, the QCL having the double-sided metal waveguide resonator shows a *higher* threshold current density (that is, it performs *less efficiently*) than that exhibited by the laser having the traditional single-sided surface plasmon waveguide.

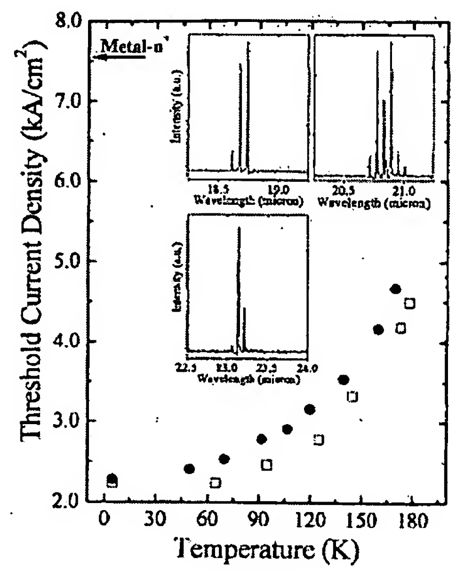

FIG. 2

Further, Figure 3 of Unterrainer, which is also reproduced here, compares the radiation intensity versus current density of a QCL having the double-sided metal waveguide (b) with one having the single-sided surface plasmon waveguide (a), tested at a wavelength of 21 microns. This figure shows that, at each of the temperatures tested, as the current density increases, the radiation intensity of the QCL with the double-sided metal waveguide drops off much more rapidly than that of the QCL with the single-sided surface plasmon waveguide. Unterrainer attributes this fast intensity drop-off to heat conduction problems within the double-sided metal waveguide and further indicates that heat dissipation problems are limiting the performance of the device. (col. 5, lines 10-21).

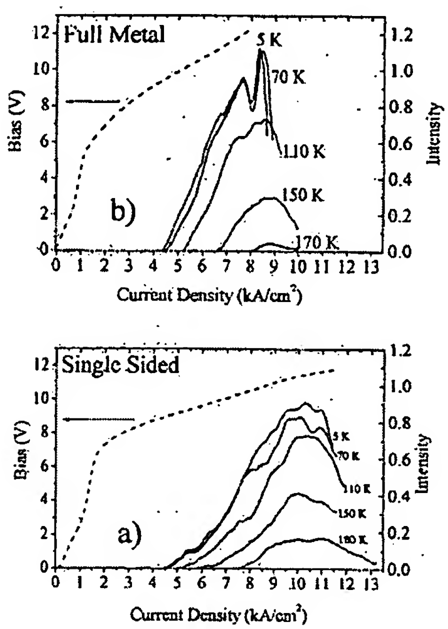

FIG. 3

In sum, the experimental data presented by Unterrainer indicates that the use of a double-sided metal waveguide, rather than a single-sided plasmon waveguide, for mode confinement can result in a degraded lasing performance.

2. *Xu does not cure the shortcomings of Unterrainer to render the claimed subject matter obvious*

Xu is generally directed to QCLs that operate in the wavelength range of 30 to 300 microns. Xu, however, is not concerned with enhancing the efficiency of mode confinement in such lasers. As such, one of ordinary skill in the art familiar with Xu would have no motivation to consider ways of improving the mode confinement of lasers disclosed in Xu, much less consider Unterrainer that is directed to a different wavelength range.

Further, as discussed above, Unterrainer would in fact dissuade one from utilizing double-sided metal waveguides in QCLs, as it provides experimental data indicating that the use of such waveguides results in less efficient lasers compared with those having single-sided surface plasmon waveguides. In other words, even if one of ordinary skill in the art would consider combining Unterrainer with Xu, she would not arrive at the claimed QCL.

3. *Response to Examiner's comments*

In response to Applicants' arguments presented in reply to the previous Office Action, the Examiner rejects Applicants' contention that Unterrainer teaches away from using double-sided metal waveguides. The Examiner states that "Unterrainer has written this article to show the potential of using the double [metal] waveguides in quantum cascade lasers of a wide wavelength ranges (abs.) to reduce waveguide losses." Further, the Examiner asserts that the "characteristics shown in fig. 2 are further explained by Unterrainer (col. 4, para 4 – col. 5, para 1), and reasons for performance, and how to enhance it, are explained."

Applicants agree that it appears that Unterrainer's article relates to an investigation of the use of double-sided metal waveguides in QCLs. Based on the presented data, however, the investigation shows that double-sided metal waveguides are less efficient than single-sided surface plasmon waveguides. In particular, as indicated above, the experimental data of Figures 2 and 3 of Unterrainer clearly show that, over the entire tested temperature range, the laser having the double-sided metal waveguide performs less efficiently than the one having a single-sided surface plasmon waveguide.

Further, the passage to which the Examiner refers simply provides speculative ideas regarding reasons for the worse performance of the QCL having a double-sided metal waveguide. Unterrainer provides some potential explanations for the less efficient performance of the double-sided metal waveguide, but does not offer any concrete guidance as to how to improve the device. Even if Unterrainer had provided more clear suggestions regarding how to improve the performance of the QCL having the double-sided metal waveguide, one of ordinary skill in the art would have no motivation to expend resources to implement such suggestions because she could simply employ the single-sided plasmon waveguide that, according to the Unterrainer data, already provides better performance.

4. *Conclusion*

Accordingly, claim 1 and claims 2-6 and 8, which depend on claim 1, are patentable over the cited art.

B. CLAIMS 15 AND 17 ARE NEITHER ANTICIPATED (35 U.S.C. §102(B)) NOR RENDERED OBVIOUS (35 U.S.C. §103(A)) IN VIEW OF UNTERRAINER INDIVIDUALLY, OR IN COMBINATION WITH XU

As noted above, independent claim 15 recites a method of confining a mode profile of radiation in a quantum cascade laser by disposing an active region of a quantum cascade laser *operating in a frequency range of about 1 THz to about 10 THz* between an upper metallic layer and a lower metallic layer, wherein each metallic layer has a thickness larger than a skin depth of radiation in said frequency range. Claim 17 depends on claim 15, and further recites employing a wafer bonding technique to generate the upper and lower metallic layers.

As discussed above, Unterrainer does not teach QCLs operating in a frequency range of about 1 THz to about 10 THz. Rather, it is directed to QCLs operating at much higher frequencies. As such, it does not anticipate claim 15, or claim 17 that depends on 15.

Nor does the combination of Unterrainer and Xu render claim 15 obvious. Whereas claim 15 recites disposing an active region of a QCL operating in a *frequency range of about 1 to 10 THz* between two metallic layers, each having a thickness larger than the radiation depth in that frequency range, Unterrainer teaches *away* from the use of double-sided metallic waveguides for confining radiation modes in QCLs. Nor does Xu teach or suggest such a feature.

Thus, claims 15 and 17 are patentable over the cited art.

C. CLAIMS 1, 4, 6, 9-13 AND 18 ARE NOT OBVIOUS (35 U.S.C. §103(A)) OVER XU AND UNTERRAINER

1. The above reasoning applies equally to establish patentability of claims 1, 4, 6, 9, and 13

As discussed above, the combined teachings of Unterrainer and Xu fail to teach or suggest at least one salient feature of claim 1: a waveguide formed of an upper metallic layer and a lower metallic layer for confining selected modes of lasing radiation within an active region of a quantum cascade laser that generates radiation in a frequency range of about 1 to about 10 Terahertz.

Hence, independent claim 1, and claims 2-4, 6, 9 and 13, which depend either directly or indirectly on claim 1, distinguish patentably over the cited art.

2. *Claim 18 is patentable over the combined teachings of Xu and Unterrainer*

Independent claim 18 recites a terahertz amplifier that includes an amplification region for amplifying an incoming radiation signal having a frequency in a range of about 1 THz to about 10 THz to generate an amplified signal. The amplifier further includes an input port for coupling the incoming radiation into the amplification region as well as an exit port for extracting the amplified signal from the amplification region. Further, a waveguide formed of *an upper and a lower metallic layer* is disposed on opposing surfaces of the amplification region to confine radiation within that region.

The above arguments presented in connection with the other claims establish that neither Xu nor Unterrainer teaches or suggests utilizing double-sided metal waveguides for confining radiation within an amplification region suitable for amplifying radiation in a *frequency range of about 1 THz to about 10 THz*. In fact, as noted above, Unterrainer teaches away from the use of double-sided metal waveguides by presenting experimental data indicating that a QCL laser having such a waveguide performs less efficiently than a comparable one employing a single-sided plasmon waveguide.

Thus, claim 18 is also patentable over the cited art.

D. CLAIM 7 IS NOT OBVIOUS (35 U.S.C. §103) OVER UNTERRAINER IN VIEW OF XU AND FURTHER IN VIEW OF KNEISSL

Claim 7 depends on claim 5, which depends, in turn, on claim 1. Claim 5 further recites that at least one of the metallic layers comprises a single layer structure formed of a metallic compound, and claim 7 adds that at least one of those metallic layers comprises a layer of gold disposed over a layer of titanium.

As discussed above, the combined teachings of Unterrainer and Xu fail to teach or suggest the following salient feature of claim 1, and consequently that of claim 7: a double-sided metallic waveguide for confining the lasing modes within the active region. Kneissl does not bridge the gap in the teachings of Unterrainer and Xu. More specifically, Kneissl, which is generally directed to nitride laser diode arrays, does not teach or suggest utilizing double-sided metal waveguides for confining the laser modes of those nitride laser diodes, much less the modes of QCLs operating in a frequency range of about 1 to 10 THz.

Hence, claim 7 is also believed to be patentable over the cited art.

VIII. CONCLUSION

For the reasons noted above, Appellant submits that the pending claims define patentable subject matter. Accordingly, Appellant requests that the Examiner's rejection of these claims be reversed and that the pending application be passed to issue.

IX. EVIDENCE APPENDIX

None

X. RELATED PROCEEDING APPENDIX

None

Dated: Dec. 7, 2006

Respectfully submitted,

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XI. CLAIMS APPENDIX

1. A quantum cascade laser, comprising:

an active region for generating lasing radiation in a frequency range of about 1 to about 10 Terahertz, and

a waveguide formed of an upper metallic layer and a lower metallic layer, each layer being disposed on a surface of said active region so as to confine selected modes of said lasing radiation within said active region.

2. The quantum cascade laser for claim 1, wherein said waveguide provides a mode confinement factor of about 1.

3. The quantum cascade laser of claim 1, wherein each of said metallic layers has a thickness in a range of about 0.1 to about several microns

4. The quantum cascade laser of claim 1, wherein at least one of said metallic layers comprises a single layer structure formed of a selected metallic compound.

5. The quantum cascade laser of claim 1, wherein at least one of said metallic layers comprises a multi-layer structure, the layers being formed by at least two different metallic compounds.

6. The quantum cascade laser of claim 4, wherein at least one of said metallic layers comprises a layer of gold.

7. The quantum cascade laser of claim 5, wherein at least one of said metallic layers comprises a layer of gold disposed over a layer of titanium.

8. The quantum cascade laser of claim 1, wherein said active region comprises a semiconductor heterostructure providing a plurality of lasing modules connected in series.

9. The quantum cascade laser of claim 4, wherein each lasing module comprises

a plurality of quantum well structures collectively generating at least an upper lasing state, a lower lasing state, and a relaxation state such that said upper and lower lasing states are separated by an energy corresponding to an optical frequency in a range of about 1 to about 10 Terahertz, and

wherein electrons populating said lower lasing state exhibit a non-radiative relaxation via resonant emission of LO-phonons into said relaxation state.

10. The quantum cascade laser of claim 1, further comprising two contact layers each disposed between a surface of said semiconductor heterostructure and one of said metallic layers.

11. The quantum cascade laser of claim 10, wherein each contact layer comprises a heavily doped semiconductor.

12. The quantum cascade laser of claim 11, wherein said heavily doped semiconductor layer comprises a GaAs layer having a doping level of about 10^{18} cm^{-3}.

13. The quantum cascade laser of claim 9, wherein said semiconductor heterostructure is formed as alternating layers of GaAs and $Al_{0.15}Ga_{0.85}As$.

14. The quantum cascade laser of claim 9, wherein a vertical optical transition between said upper lasing state and said lower lasing state generates lasing radiation in a range of about 1 THz to about 10 THz.

15. A method of confining a mode profile of radiation in a quantum cascade laser, comprising:

disposing an active region of a quantum cascade laser operating in a frequency range of about 1 THz to about 10 THz between an upper metallic layer and a lower metallic layer,

wherein each metallic layer has a thickness larger than a skin depth of radiation in said frequency range of about 1 THz to about 10 THz in said metallic layer.

16. The method of claim 15, further comprising forming said active region by molecular beam epitaxy.

17. The method of claim 15, further comprising employing a wafer bonding technique to generate said upper and lower metallic layers.

18. A Terahertz amplifier, comprising

an amplification region for amplifying an incoming radiation signal having a frequency in a range of about 1 THz to about 10 THz to generate an amplified signal,

an input port for coupling said incoming radiation into said amplification region,

an exit port for extracting said amplified signal from said amplification region, and

a waveguide formed of an upper and a lower metallic layer diposed on opposing surfaces of said amplification region to confine radiation within said amplification region.

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